

## ABSTRACT

BUTLER, COLIN GRANT. Exploring Bimanual Tool-Based Interaction in a Drawing Environment. (Under the direction of Robert A. St. Amant.)

In this document, I will present HabilisDraw DT, a drawing environment in which bimanual direct manipulation and a strong tool-use metaphor are supported via the DiamondTouch input device from Mitsubishi Electronics Research Lab. The goal of this research is to explore the viability of the various contributions of HabilisDraw DT in the development of future interfaces. The principles upon which HabilisDraw DT have been built include persistent tools that embody intuitive aspects of their physical counterparts and an approach to interface learnability that capitalizes on the user's inherent ability to use tools both separately and in conjunction with other tools. In addition to these principles, HabilisDraw DT extends the physical-virtual tool correlation with bimanual input via the MERL DiamondTouch input device and a close adherence to the direct manipulation interaction model. This paper presents background work in novel interaction and an overview of the HabilisDraw interface, then explores the benefits of a desktop metaphor that closely mimics the behavior of tools and objects in a two-dimensional drawing environment and argues for the applicability of the system's fundamental principles for improving interface usability in the future.

**EXPLORING BIMANUAL TOOL-BASED INTERACTION IN A DRAWING  
ENVIRONMENT**

by

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Chair of Advisory Committee

## **Biography**

Colin Grant Butler was born in Beaumont, Texas on November 25, 1980. His family moved to Springfield, Missouri in 1986 and then to Clemmons, North Carolina in 1993. After four years at West Forsyth High School, he decided that he wanted to study Computer Science at North Carolina State University in Raleigh.

Colin spent four years earning a Bachelor of Science degree in Computer Science with a minor in English, graduating Magna Cum Laude in May 2002. He has spent the past two years researching applications of tool use in novel user interfaces for his Master's Degree at NCSU under Dr. Robert St. Amant.

Upon completion of the requirements of his degree, Colin intends to move to Durham, North Carolina and seek a job in the Raleigh-Durham area developing software.

## Table of Contents

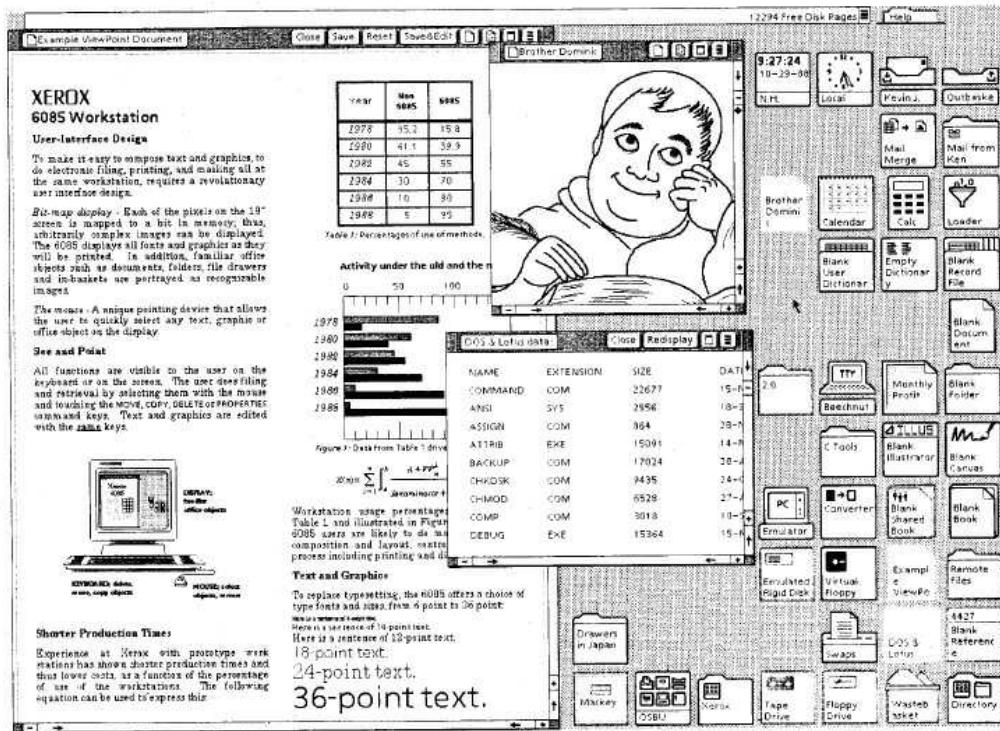
LIST OF TABLES	iv
LIST OF FIGURES	v
1. INTRODUCTION	1
2. RELATED WORK	3
2.1. Bimanual interaction	3
2.2. Tool use	3
3. SYSTEM DESIGN	5
3.1. Theory	5
a. Direct manipulation	5
b. Bimanual interaction	6
c. Tool use	7
i. A tool taxonomy	7
ii. Characteristics of tool use	9
3.2. History	15
a. HabilisDraw v1.0	16
b. HabilisDraw v2.0	19
3.3. Hardware	21
3.4. Software	23
a. Conceptual overview	23
b. Class structure	29
c. Implementation notes	31
4. EXPERIMENT	33
5. RESULTS	36
5.1. Action observations	37
5.2. Object observations	39
5.3. Interface observations	40
5.4. Approach observations	42
6. ANALYSIS	44
7. CONCLUSION	49
8. REFERENCE MATERIALS	52
Appendices	
A. Study Questionnaire	54
B. Questionnaire Responses	56

## **LIST OF TABLES**

Table 1: A qualitative comparison between drawing environment interactions in HabilisDraw DT and standard direct manipulation interfaces.	44
Table 2: Quantitative overview of survey demographics and responses	49

## **LIST OF FIGURES**

Figure 1: The Xerox Star interface.	1
Figure 2: The tools of HabilisDraw v1.0	17
Figure 3: A composite tool for creating spirals.	19
Figure 4: The default HabilisDraw DT desktop.	25
Figure 5: Holding an object (in this case, a pen) shows a transparent “iconic display” of the object in hand	29
Figure 6: An expert drawing done with HabilisDraw DT.	33
Figure 7: A user performing a pattern matching task in HabilisDraw DT.	34
Figure 8: A user creating a house in HabilisDraw DT.	35
Figure 9: The selection of experiment patterns.	36



*Figure 1: The Xerox Star interface.*

## **1. INTRODUCTION**

In 1981, Xerox released the Star interface to the public [Johnston, et al., 1989]. With this release, Xerox pioneered bitmapped interfaces and the desktop metaphor, setting into motion the evolution of consumer user interfaces for the next two decades. Its influences were immediately visible in the Macintosh operating system, released in 1984, and Microsoft's Windows operating system, along with many other less-popular systems in following years, such as GEOS, released in 1986 for the Commodore 64 and BeOS, released in 1998 for x86 systems. The wildfire spread of the desktop metaphor demonstrates the power of familiarity in user interfaces. By designing the interface of this new kind of operating system around the natural interactions with a desktop, users unfamiliar with the concept of a bitmapped user interface could better understand many aspects of its operation.

without consulting a user manual and learning by rote. Since then, research has continued to search for ways of improving usability and learnability in user interfaces. Even very strictly limited subsets of a human’s output capabilities far surpass the ability of most interfaces to capture and interpret input. If interface designers can capitalize on this strength, the conceptual and practical domain of user interaction could very well extend far beyond the limitations of current mouse and keyboard methods.

Humans are tool-using creatures. The application of a tool to a desired end is an ability long developed in our evolution as a species, providing a method by which our impressive manual dexterity and advanced intellect can act on physical objects and principles to increase the efficiency, magnitude, or speed of an operation beyond our own physical limitations. In this paper, I will describe the HabilisDraw DT system I have developed over the course of my graduate studies. HabilisDraw DT is designed around a set of fundamental principles regarding the use of physical tools with the intent of exploring the effects of presenting a common computing task, i.e. drawing, as a tool use problem. The intent behind casting the drawing task as a tool using task is to exploit user familiarity with the use of tools as functional enablers to improve learnability and usability within a limited domain with the potential to extend the more beneficial principles to other applications. Examining user interactions with this task should help provide insights regarding which aspects of the model serve this purpose better than others and how we might be able to better implement the principles that can or do provide significant benefits.

## **2. RELATED WORK**

### **2.1 Bimanual Interaction**

The most familiar work on bimanual interaction is probably due to Xerox PARC, in the Toolglass™ and Magic Lenses™ system [Bier, et al., 1993]. The design of this system uses a trackball for the non-dominant hand, controlling a transparent tool palette; and a mouse for the dominant hand, controlling the primary cursor. The palette can be configured to provide one of many functionalities, either active (e.g. click-through tool functionality) or passive (e.g. Magic Lenses™). By selecting a tool for the palette and positioning it over the object of interest with one hand and clicking “through” the palette with the other hand, many of the inefficiencies of a modal interface are streamlined into an intuitive bimanual interface. Alternatively, the palette can be configured to act as a “Magic Lens™,” representing some alternative mode of display for all objects beneath it.

In other bimanual interaction related work, Cutler et al. developed a system called the Responsive Workbench [Cutler, et al., 1997], for which they developed a two-handed three-dimensional user interface for medical training and automotive design applications. Both hands are used to manipulate both the user’s perspective and the virtual objects on a 3D tabletop display. The system supports a set of unimanual actions and sets of both bimanual symmetric and asymmetric actions. The various actions are represented as tools in a toolbox, where the user can choose an operation and apply it via hand gestures.

### **2.2 Tool Use**

In the area of tool-based interaction, one well-known related system is Bederson et al.’s KidPad [Bederson, et al., 1996], in which tools are first class objects that can be picked

up and manipulated like other objects in the interface, in contrast to more common menu- or palette-based “tool mode” designs. The system uses multiple mice to provide a collaborative storytelling interface where children can use Bederson’s own “local tools” to develop stories comprised of images, text, and spatial arrangement.

Later, I will discuss another tool-based project, the original HabilisDraw [St. Amant and Horton, 2002], which is a tool-based 2D drawing program developed by Robert St. Amant and Thomas Horton upon which HabilisDraw DT is based.

There are several projects that focus on bimanual interaction, and a limited number of these projects *use* tools, but there are very few projects that use *tool-based* bimanual interfaces. The Toolglass project previously mentioned is arguably tool-based, but also bears several characteristics of a standard interface with a special tool provided for the non-dominant hand. Roope Raisamo’s alignment stick project [Raisamo, 1999] is one project that currently supports bimanual interaction in a specifically *tool-based* environment. Raisamo’s system allows users to create drawings by manipulating a set of tools in the form of various types of stick. The primary difference between Raisamo’s interface and the HabilisDraw DT interface is that the HabilisDraw DT system uses the MERL DiamondTouch to provide interaction through direct contact.

Additionally, Patten et al. have developed a hardware system called Sensemable [Patten, et al., 2001], which electromagnetically tracks tangible interface objects on a tabletop and projects relevant information directly onto the tools themselves. Their system supports direct bimanual manipulation of interface tools with no mediation or indirection

whatsoever. This approach easily and effectively addresses the formidable issue of capturing a user's natural ability to operate upon multiple degrees of freedom concurrently.

### **3. SYSTEM DESIGN**

#### **3.1 Theory**

##### ***3.1.1 Direct Manipulation***

In 1983, Ben Shneiderman [Shneiderman, 1983] outlined a new interaction model for what he called “direct manipulation.” The principle of direct manipulation is somewhat self-explanatory: it values direct interaction and locality over abstraction and obfuscation. The three fundamental properties of a direct manipulation system are as follows:

1. Continuous representation of the object of interest
2. Physical actions or labeled button presses instead of complex syntax
3. Rapid incremental reversible operations whose impact on the object of interest is immediately visible.

By defining this new model, Shneiderman provided a set of principles by which users could easily associate objects with their states and actions with their effects. Since then, direct manipulation has been one of the dominant models in interface design.

Shneiderman claims several benefits to applying direct manipulation to an interface. For instance: learnability is improved, operational concepts are better retained, error messages are required less often, and users are better informed of the status of their active tasks. While exact efficiency depends on both the user and the domain and design of the interface beyond just its interaction model, building upon the direct manipulation concepts provides a basis by which very functional user-friendly interfaces can be designed.

### ***3.1.2 Bimanual Interaction***

In a paper written for the CHI human-computer interaction conference in 1986, Buxton and Myers [Buxton and Myers, 1986] performed a study in which they showed that two-handed input provides at the very least an improvement in efficiency for users performing a set of continuous tasks representative of CAD and office informational work. The experiments involved the use of either one or both hands for one of two tasks. In the first experiment, users were asked to position and scale a square bracket to match a provided example. This experiment was performed bimanually by all subjects, using a treadmill-like slider in the left hand for scaling and a puck in the right hand for positioning the object. The second experiment involved a document scrolling and selection task, dividing users into single-handed and two-handed groups where the single-handed users scrolled using the puck and a classic scrollbar and two-handed users used a touchpad with their left hands. Users were asked to scroll to a specified line in the document and highlight one of the three words (“left,” “middle,” or “right”) on the line. The results of the experiment showed that in experts, two-handed operation improved performance by 15% and in novices, two-handed operation improved performance by 25%. In one-handed experiments, experts outperformed novices by 85%, while in two-handed experiments, the difference was only 32%. For any given subject, the best performance was always on a two-handed trial. All of the data support the claim that the ability to use both hands, even when the capabilities of each hand are asymmetric and strictly limited to a subset of actions, provides a significant advantage over using only one hand.

Soon after Buxton and Myers' study, Yves Guiard wrote a paper in 1987 [Guiard, 1987] proposing a new theory of bimanual action, in which the non-dominant hand is regarded as a lower-ranking motor in the kinematic chain of action, ranking directly below the dominant hand and performing supporting actions that are temporally and spatially precedent as well as relatively spatially coarse with respect to the higher ranking motor that is the dominant hand. In forming a basis for this proposition, Guiard argues that defending the claim that any human manual action is executed entirely by one hand with no role whatsoever performed by the other is difficult, if not impossible. The claim effectively reduces the classification of manual tasks from unimanual, bimanual symmetric, or bimanual asymmetric to a simple distinction between symmetric and asymmetric, where actions formerly classed as unimanual are assigned to the class of bimanual asymmetric actions, assuming that the non-dominant hand plays some sort of subtle balancing, supporting, or positioning role in the task at hand.

### **3.1.3 Tool Use**

#### **3.1.3.1 Tool Taxonomy**

In a paper on tool-based direct manipulation environments [St. Amant and Horton, 2004], Robert St. Amant and Thomas Horton outline a domain-dependent taxonomy of tools that is applicable to both physical tools and software interaction methodologies. Tools in this taxonomy are divided into four groups according to the intended function to which they are applied. Because of this, a tool may be categorized under one group by default for its intended function, but then be applied as a different type of tool on an ad hoc basis. For example, a ruler may act as an *instrument* by providing spatial information about its

environment, but then act as a *compensating* tool when one constrains a pencil line against its edge.

- *Effective tools.* An effective tool is a tool that produces a persistent effect on another entity within the environment, including the environment itself. This category includes many of the most popular physical tools such as hammers, saws, screwdrivers, and any other tool designed to facilitate an action or magnify an applied force.
- *Instruments.* The category of instruments includes any tool whose purpose is to provide information about the environment that might otherwise be less available or less reliable. Measuring tools, magnifying tools, finders, and diagnostic equipment fall under this category.
- *Compensating tools.* Tools which aid in the application of effective tools by constraining motion or limiting the application of an effective tool are called compensating tools. The class of compensating tools encompasses clamps, stencils, guides, and supports. St. Amant also points out that many tools have an inherent compensation factored into their design. A handsaw, for instance, cuts a long groove into which the blade fits in repeated strokes. This groove maintains the angle and consistency of the cut's progress, thus compensating for any instability that might otherwise yield a change in the direction of the cut. In saws designed to accommodate changes in the direction of the cut, the blade is much narrower, relaxing the constraint.
- *Demarcating tools.* These tools are designed to mark or differentiate between elements or areas in the environment which may otherwise be difficult to

distinguish or navigate. Demarcating tools are categorized separately from effective tools because all tools in the set do not necessarily leave a permanent mark, but the goal of demarcation is common across the entire set. Grease pencils, flags, and marked or graduated surfaces all belong to the set of demarcating tools.

### 3.1.3.2 *Characteristics of Tool Use*

Applying a conceptual tool use model to an interface can be managed in many cases with a relatively shallow model. In the design of most direct manipulation interfaces, tools simply act the part of an action translation interface between the user's input and a virtual domain-specific effect. Selecting the pencil tool in Adobe Photoshop causes a click-and-drag motion to translate to a simulated pencil mark along the line of motion, for example. For HabilisDraw DT, however, more consideration was put into developing tools that act as persistent entities within the environment instead of an intermediary between the user and the simulated environment. Using an object as a tool in HabilisDraw DT is not a matter of applying its effect to the environment or the mode of the cursor; instead, it is an action executed by the user on or with the tool object. In many cases, these actions are compositionally complex: the user can pick up a pen and execute a drawing action *with* the pen *on* the paper while *constrained by* the ruler. Tools have function both as a result of their status as an object, in that all objects mask pen marks against objects underneath them, and as a result of special functional attributes provided by their status as a specific tool class. These special traits are generally the implementation of the tool's designated purpose, such as the tape dispenser's ability to join pieces of paper together.

Besides modeling how the tools act, a fully tool-based interface must model how the user interacts with the tools in the general case. For this purpose, St. Amant describes a set of characteristics of tool use that define user interactions with tools and tool interactions with other objects in the environment. Applying this set of characteristics to HabilisDraw DT ensures a user experience that is markedly more consistent with the use of tools in the real world than most interfaces. The following list describes each characteristic and how HabilisDraw DT attempts to implement it in a virtual environment.

- *Object status and manipulability.* All entities in HabilisDraw DT (except for indicators of left- and right-hand contents) are physically manifest objects, and as such are manipulable in most cases. The only non-manipulable object is the trash can, which is locked in place and cannot be used or affected by other objects.
- *Affordance.* Gibson [Gibson, 1979] and Norman [Norman, 1999] have described affordances roughly as indicators of how an object can be used. Handled objects exhibit affordances for grasping via the dimensions of the handle being a suitable spatial match for a closed hand. Since representing affordances visually with respect to the spatial dimensions of the HabilisDraw DT inputs (i.e. four one-dimensional points with two translational degrees of freedom each) would be difficult and unintuitive, indications of a tool's function must be represented in another way. By designing all tools to roughly match the appearance of their physical counterparts and designing interaction gestures with the system that mimic physical actions, the user's

familiarity with the physical versions of the tools and the affordances associated with each can be used in place of direct input-to-object affordances.

- *Specialized action.* This denotes a link between the spatial characteristics of the object and the action required to use it. Given the limited scope of motions available on a two-dimensional surface, HabilisDraw DT attempts to support specialized action for all manipulable tools. The set of motions a single finger can execute is limited to: initiating contact, terminating contact, and moving in two dimensions. If we consider initiating and terminating contact to be opposing motions on the z axis, then many basic three-dimensional physical actions can be approximated. For a tool such as the cutting arm, the executing action is a motion on the z axis, so it is activated by initiating contact. For tape, the executing action is a motion between objects. In HabilisDraw DT, all objects are situated on the x-y plane, so motion on that plane between two or more objects operates the tape.
- *Open-loop versus closed-loop action.* Closed-loop actions are actions in which the feedback is incorporated into mental operations to refine the action for future use. Taking “practice swings” in golf or with a hammer are examples of closed-loop actions. Open loop actions occur post-calibration, when the output of the action is the desired effect. This equates to the final stroke in which the user hits the golf ball or strikes the nail into the board.
- *Effect locality.* Physical objects cannot affect objects that do not share contact with them. In the case of air hoses, torches and other indirect tools, a chain of interactions between intermediate molecules in contact with each other leads

eventually to a local interaction at the target. These cases are potentially visually deceptive (with no other cues, objects pushed by air give little indication of the cause of their motion), so HabilisDraw DT ignores this case. For most tools, the tool itself must come in direct contact with its target to have an effect. If swinging a hammer through the air would drive a nail into a board in another room, tool use would be a difficult task for nearly anyone. Many interfaces ignore the concept of effect locality, letting dialog boxes alter the properties of an object whose location is completely independent of the dialog's location. HabilisDraw DT respects locality by letting objects only affect objects that are in contact with each other. This requires the assumption that when an object is “picked up,” its location is instantaneously associated with the index finger contact of the hand that is holding it.

- *Iteration.* Due to locality, many actions must be repeated for iterative progress or multiple targets. A hammer cannot hit every nail in a board at the same time without being unrealistically large. HabilisDraw DT, in supporting locality, supports iteration as well.
- *Material consolidation.* Sometimes it is beneficial to consolidate materials as the combined target of a single action instead of repeating the action once for each material. Doing so can improve efficiency as well as accuracy when an unreliable motion could create errors between the successive outcomes of iterative actions. By simulating two dimensional space and allowing for overlapping objects, HabilisDraw DT supports material consolidation in tasks

such as cutting multiple sheets of paper to equal lengths and marking across multiple sheets of paper.

- *Variation and duplication.* Using a magnetic screwdriver with interchangeable bits can save space in a workshop, but having a set of non-configurable screwdrivers can be considerably more efficient than changing bits every time a different size of screw is encountered. In the case of a large or messy workshop, having multiple sets of screwdrivers would further improve efficiency by providing more instances of each screwdriver and thus making it easier to find the screwdriver needed for the task at hand. In HabilisDraw DT, pens, paper and inkwells all support variation and duplication. All of these can be varied in color, and multiple instances of each are provided; in the case of the paper, a limitless supply is available to the user.
- *Adjustability and composability.* Composability can be expressed both by compound tools created by combining simpler components and by augmented tools wherein a tool's basic functionality is improved by the extension of its functional principles. A makeshift compass made from string tied to a pushpin at one end and a pencil at the other is an example of a compound tool. A plane or scraper can be struck with a hammer to augment the blade's cutting ability when it becomes difficult to push by hand. HabilisDraw DT supports compound tools in a limited capacity by allowing users to tape paper together to form complex stencil masks. HabilisDraw DT's support for tool

augmentation has been demonstrated in an observational study by the alignment of a ruler with the cutting arm to improve the accuracy of cuts.

One result of designing a fully tool-based interface is an inclination towards non-modal operation. In the case of a graphics package such as Adobe Photoshop, tools are designated by buttons that alter the user’s interaction mode. By clicking the marquee tool, the mouse cursor becomes a selection tool and the command set provided by the keyboard and menus is configured to support the selection task. When operating in the selection-creation mode initiated by selecting the marquee tool, for example, clicking and dragging creates a new selection and the shift key can be used to constrain the aspect ratio of the selection to 1:1. Upon selecting a region, the interaction mode changes to a selection-manipulation mode, at which point clicking and dragging creates a new selection that replaces the existing selection and the shift key can now be used to select a Boolean union of the existing selection. Each mode change immediately annuls the effects of the previous mode. Since a tool represents nothing more than a mode change, no interaction at all is supported between tools.

In a tool-based system such as HabilisDraw or HabilisDraw DT, tools are persistent and the user’s input is modeless. Any time the user chooses to perform a particular gesture with respect to a tool, object, or configuration of objects, the result is the same, assuming only that the user is “holding” the same tool or object while performing the gesture. While it is true that the modality of many user interfaces is designed to mimic the concept of holding a tool, the need for increased complexity in many such interfaces has overwhelmed this intention and layered a number of additional modal interactions on top of the basic

application of the tool, leading to a style of interaction more closely mimicking a global mode change rather than the selection of a single non-modal tool. The design of HabilisDraw attempts to compensate for the loss of complexity suffered in providing non-modal tools by supporting parallelism through bimanual interaction as well as tool composability.

As we will see later, there are many benefits and disadvantages to applying a strict tool-based approach to interface design. However, by doing so, we can isolate the effects of tool use from the idiosyncrasies of an interface and determine how we can improve future interfaces through the intelligent application of some of the principles inherent to tool-based designs.

### 3.2 History

HabilisDraw DT is derived from the original HabilisDraw system, designed and implemented by Dr. Robert St. Amant and Thomas E. Horton. The original HabilisDraw is a two-dimensional drawing environment that uses mouse input to operate a set of persistent tools on a “paper” background. It was designed to explore the tool use metaphor in human-computer interaction in an attempt to better define the concept of tool use with respect to software functionality and to develop a better understanding of the potential benefits of applying the tool use metaphor to the design of future interfaces. In these respects, the DiamondTouch variant of HabilisDraw discussed in this paper is very similar in purpose to the original HabilisDraw project. In this section, I will describe the first two iterations of the original HabilisDraw system, simply known as HabilisDraw v1.0 and v2.0.

### **3.2.1 HabilisDraw v1.0**

Version 1.0 of HabilisDraw provides the user with a set of tools and a drawing environment in which he or she can create, position, and use these tools. Using a pen, the user can draw a freehand line. By positioning a ruler in the workspace, the pen can be constrained to draw along the edge of the ruler. Such actions demonstrate the interaction between tools in the system, defying hierarchical or subdivided classification of the available tools. The user can interact with a tool in a relatively non-modal context (picking up a tool could technically be considered modal and mouse-down effects could similarly be seen as modal, but actions are generally effected via a non-modal “hand”) and the tools can interact with each other to produce complex behavior. Tools do not necessarily need to be “activated” to have an effect on other elements of the system (e.g. a ruler acts as a straightedge without requiring activation), but effective tools can be moved and positioned freely without interacting with the environment accidentally.

All of the tools originally incorporated into HabilisDraw mimic a real world drawing tool in title and function. The representation of each tool, shown in Figure 2, is not necessarily tied directly to the physical appearance of the tool due to either a difference in the function of the tool or an inherent difficulty in applying some representations (e.g. a compass, which extends into the z axis when in use) to a 2D drawing environment. In cases such as these, tool graphics were designed to convey their intended use visually and in an easy to understand manner. Note that in the following list, tools are described as they appear in the original HabilisDraw system. In version 2.0 of the system, some aspects of various tools were altered.

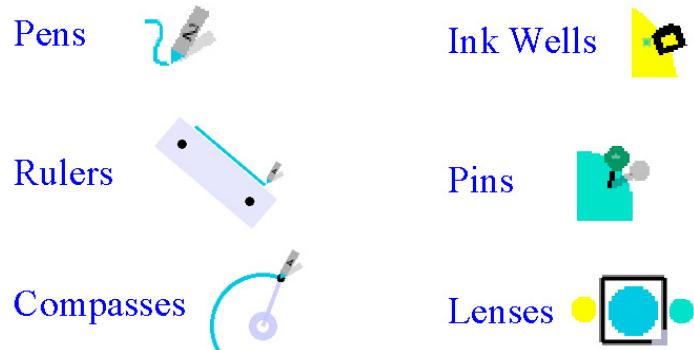


Figure 2: The tools of HabilisDraw v1.0

- *Pens*. When activated over the drawing surface, a pen in HabilisDraw will leave a mark in its specified ink color. When used in conjunction with a ruler or a compass, the pencil’s motion can be constrained to a straight line or either a circle or an arc, respectively. By activating the pen over an inkwell, the pen can be “dipped” to acquire the color of the ink in the well, and multiple instances of different colors of the pen tool can be left on the workspace, but only one can be activated at a time.
- *Inkwells*. Inkwells can be used in conjunction with pens to change the color of the pen as described previously, or to change the color of a shape. When the user picks up and activates an inkwell over a drawn object, the object changes color to that of the ink in the well.
- *Pushpins*. Pushpins can be placed on an object to provide handles by which the object’s position can be manipulated by hand if the user moves the pushpin itself or constrained if the user attempts to move the object under the pushpin.
- *Compasses*. By placing the center of the compass, adjusting the length of the arm and using a pen on the end of the arm, the user can draw any arc of a circle by dragging

the pen. The compass constrains the attached pen to a circle around the compass center of the radius specified by the arm length. By clicking the center of the compass, the user can toggle the ability to sweep out filled arc instead of an outline.

- *Rulers.* A ruler in HabilisDraw has two handles, one at either end. By dragging a handle, one end of the ruler will move and the other will remain stationary, allowing the user to rotate and adjust the length of the ruler. If the user drags anywhere on the ruler except for the handles, the ruler can be dragged anywhere on the workspace without changing its orientation or length. While moving or stationary, the ruler constrains objects against its edge, allowing the user to draw straight lines with a pen or align objects by pushing the ruler against them.
- *Lenses.* A lens allows the user to magnify a section of the workspace. The magnification level is user-adjustable and the lens can be freely positioned by hand over any part of the workspace.

The selection of tools developed for the original version of HabilisDraw was used as a guide by which the set of tools in HabilisDraw DT were chosen. Over the course of the design, however, it became clear that a new approach would be necessary to extend the model to a stricter implementation of the principles of direct manipulation. As a result, several new tools and objects were added to the design of HabilisDraw DT in order to support these extensions. At the same time, implementing certain other tools proved technically or conceptually prohibitive given the timeline and computational constraints of the project. Thus the final set of tools provided with HabilisDraw DT differs considerably

from the original toolset of HabilisDraw, but there still exist a number of tools shared between the two: namely, pens, inkwells, and the ruler.

### 3.2.2 *HabilisDraw v2.0*

Shortly after the initial development of HabilisDraw v1.0 completed, the project was extended by John Daughtry [Daughtry and St. Amant, 2003] to include several new tools under the class “power tools,” which improved composability and added a level of automation to the original design. Where version 1.0 of HabilisDraw is mostly limited to freehand, straight lines, and arcs all drawn by hand, version 2.0 added the ability to create a rigid bar, attach pens to it, and combine it with movers and rotators to automatically draw lines according to the motion defined by the attached movers and rotators. These extensions allow for the creation of regular designs, such as spirals, that would otherwise be very difficult to create in any drawing environment. Additionally, by attaching pens to a bar tool and manipulating the bar, repetition can be spared when multiple identical markings are desired.

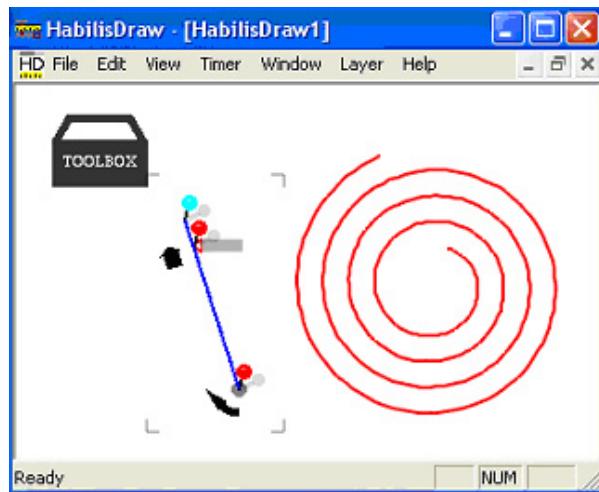


Figure 3: A composite tool for creating spirals.

- *Bar tool.* The bar tool allows the user to draw a line that then becomes an object in the environment to which several tools can be attached via pushpins. By attaching a pen, the bar can be used as a constraint for that pen. If multiple pens are attached, they are constrained relative to the bar and each other so that the user can draw multiple lines in parallel.
- *Bezier bar tool.* Similar to the normal bar tool, the Bezier bar tool can be used to create a rigid bar object, except that the bar can be specified as a Bezier interpolated curve. Once defined, it behaves exactly like a regular bar.
- *Mover.* The mover is a tool that can be placed on the work surface and configured to move linearly, pushing objects along its way. By attaching a mover to a bar tool, the bar can be made to trace out a straight line across the desktop. In addition, the bar tool can provide a linear impetus to the end of a bar, shrinking or enlarging it over time.
- *Rotator.* Similar to the mover, the rotator can be used to set other tools in motion. A rotator attached to a bar tool can provide an automated method for drawing circles. Adding a mover to the end of the bar to change its length as it rotates allows the user to create spirals, which are otherwise extremely difficult to create.

One of the main focuses of HabilisDraw v2.0’s design was extending and empowering the tool-based metaphor by providing tools that encourage composition and a hands-off approach to more complex tasks. The addition of “power tools” served to explore ways of bridging the gap between the simpler but more intuitive interface of the original

HabilisDraw and the more complicated functionality of commercial graphics packages. HabilisDraw DT's design does not take power tools into account, taking a step back from a functionality-oriented design to explore some of the more fundamental concepts advanced by version 1.0 of the system, but adding an additional layer of interactivity through a more literal simulation of a desktop workspace. By examining the application of these novel interaction principles, I hope to provide some degree of insight for future research on the best way to begin increasing the power and complexity of the tool set.

### 3.3 Hardware

Tracking multiple inputs on a computer can be extremely difficult. Multiple pointers are often distracting and hard to track and controlling these pointers with mice or trackballs requires a large amount of space in addition to the display. In 2001, Mitsubishi Electronics Research Lab released a paper and prototype for the DiamondTouch multi-user collaborative input device [Dietz and Leigh, 2001]. The design provided a touch-sensitive display surface that supports input from multiple users simultaneously. Since then, the device has been developed into a release state and has seen limited distribution. The current form of the device comes in two models: DT88 and DT108, with 88cm and 108cm diagonal measurements respectively. Display is provided by an overhead-mounted projector aimed (or reflected) at the reflective white input surface, allowing users to operate an interface by simply touching various components directly.

The DiamondTouch detects user contact via capacitive coupling between the user and an array of antennas under the surface. In order to form the capacitive circuit, the device must pass a low-power electrical signal through each user, encoding a unique “spreading code”

that allows that user's contact to be distinguished from another's. This signal is typically applied by having the users sit on specially designed chair mats. For HabilisDraw DT's purposes, however, this is insufficient. HabilisDraw DT requires two distinct, unambiguous points of contact for each hand and while all aspects of the interface are operable with a single hand, the benefits of bimanual interaction cannot be explored without at least two hands of two contact points each. Since the DiamondTouch hardware has support for eight inputs, this means that HabilisDraw DT can feasibly be extended to accommodate two users simultaneously.

The primary difficulty in designing and implementing an interface that supports bimanual direct manipulation with three degrees of freedom (translation on x and y axes, rotation in x-y plane) was allowing one user to provide four unambiguous contact points on the DiamondTouch surface. The DiamondTouch uses two one-dimensional antenna arrays to return capacitive couplings that exceed a user-configurable threshold. This approach allows the user to register a single unambiguous point or a range of ambiguous x and y values. An application could attempt to match each significant x value with the appropriate y value by considering a combination of contact time and changes in reported signal power, but there are certain situations that could be ambiguous with respect to the number or location of contacts. Additionally, multiple contacts in close proximity on one axis could lead to a loss of precision in locating each point. Because of these difficulties, a pair of gloves was designed by which a single user can user two inputs per hand: one on the thumb and one on the index finger.

The gloves consist of contacts sewn into white cotton gloves with a junction box riveted to the back, where wires running from the contacts are joined to a pair of standard

RCA female jacks. The DiamondTouch device also uses RCA female jacks for inputs, so a simple RCA stereo cable or mono audio/video cable can be used to connect the gloves to it. Because the fingertip contacts require a certain amount of flexibility as well as electrical conductivity, aluminum foil is used for the contact surface. The foil can wear out with repeated use, so the fingertip contacts are held under a sleeve where they can be removed and replaced easily.

### **3.4 Software**

#### ***3.4.1 Conceptual Overview***

HabilisDraw DT provides users with the classic desktop metaphor, but with a twist. The interface is a strict interpretation of the desktop even to the extent of being textured with a wooden desktop pattern. Physical interaction with the interface is a strict interpretation of desktop interactions as well, modeling bimanual gestural manipulation of nearly every object with two degrees of translational freedom and one degree of rotational freedom. In addition, objects can be “picked up” off the desktop surface and used or put back down. Interactions such as pen drawing and cutting act realistically according to the rules of physical interaction whenever it is not impractical to obey such rules. Stacked paper can be cut simultaneously, pens can mark on any of a number of objects in any orientation while respecting depth ordering, and pieces of paper can mask objects below them from pen markings. It is on this interpretation of the metaphor that I will make observations concerning the feasibility of applying the concepts of bimanual gestural interaction and the use of familiar virtual tools on the design of future interfaces.

One of the key assertions made in HabilisDraw DT’s design is that what are commonly referred to as “tools” and what commonly act as objects of these tools belong in the same classification. The reasoning behind this is that humans have a natural inclination towards opportunistic tool use. Tool use is where one approaches a task aided by the application of some object to increase his or her own effectiveness. Opportunistic tool use is when that object is chosen as a tool based solely on the affordances it provides rather than its classification as a tool suited for the purpose to which it is applied. For example, a person may need to drive a screw, but lacking the ability to drive it effectively by hand, improves his or her effectiveness by inserting a dime into the head of the screw to increase the torque behind the turning motion. The dime is used as a tool for driving the screw, but a dime is not explicitly a screwdriver. It simply has a limited grasping affordance and a symmetry with the slot on the head of the screw that inform the user of its potential to be used as a tool for this particular task. HabilisDraw DT attempts to encourage this sort of opportunistic tool use by starting all objects off with the same basic physical attributes and behaviors, by which the user can form his or her own conceptual model and apply the objects to whatever end he or she desires. Special “tools” that behave according to a particular design, such as pens and tape, are extended from the basic object model with functional attributes that enable the tool’s specific behavior.

The set of objects and “tools” provided by HabilisDraw DT are specially selected to represent a combination of the basic tool set provided by HabilisDraw v1.0 and the tool set one might expect on an average desktop during a drawing task. The tools’ positions are marked in Figure 4 to show their locations on the desktop at startup.

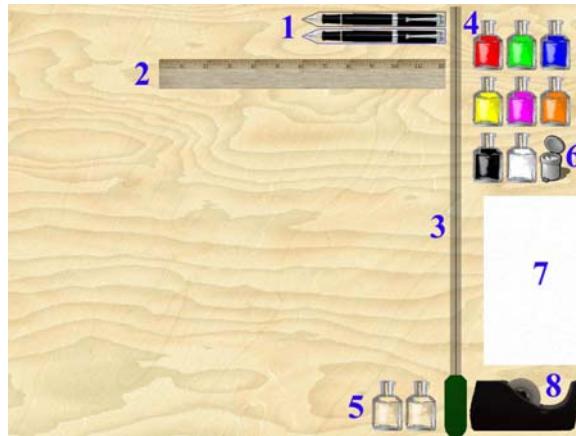


Figure 4: The default HabilisDraw DT desktop.

1. *Two pens, blue and black* – Pens can mark on any object designated as “drawable.” Objects that can reasonably be expected to receive a mark from a pen are marked as drawable: desktop, paper, ruler, etc. Pens have an outline around them that shows the color of the ink they contain.
2. *Ruler* – The ruler can be positioned freely around the desktop. When in place, it constrains pen lines to its edges if the line started from off the ruler. If the line starts on the ruler, the user is free to make marks on its face.
3. *Cutting arm (fixed)* – The cutting arm is fixed in place on the right of the workspace. When the handle is pressed, any pieces of paper spanning the vertical line traced by the arm are bisected along that line.
4. *Eight inkwells of different colors* – The inkwells at the right of the desktop represent eight common colors: red, green, blue, yellow, purple, orange, black, and white. Inkwells can be used to change the color of paper or the color of ink in a pen or another inkwell. Using an inkwell on the trash will empty its contents.

5. *Two empty inkwells* – These inkwells are provided for the user to fill and alter at will. The only difference between the empty inkwells and the filled inkwells is that they begin empty. Filled inkwells can be emptied at the user's discretion.
6. *Trash can (fixed)* – The trash can can be used to destroy any piece(s) of paper or to empty inkwells.
7. *Stack of paper* – The stack of paper represents an infinite supply of rectangular sheets of white paper. By dragging off the top of the stack, the user can spawn a new sheet of paper quickly and easily.
8. *Tape dispenser* – When the user picks up the tape dispenser and uses it in a line across the desktop, all pieces of paper under the line are instantly joined together and their relative orientations are fixed. Thus when two sheets of paper are taped together and one is rotated, the other rotates with it.

The object class in HabilisDraw DT provides a certain level of functionality for every object unless it is specifically disallowed by the specification of the object. For example, most objects can be moved and rotated unless they are marked otherwise. The general set of actions allowed by the interface is as follows:

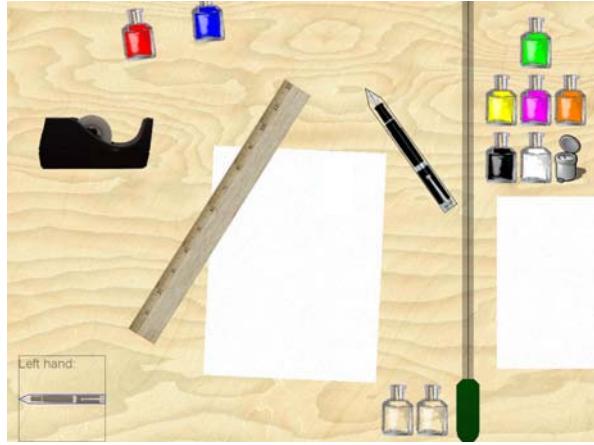
- *Moving an object* – The user can move an object by simply placing any thumb or forefinger down on an object and sliding it along the desktop. The orientation of the object is not affected by this movement; only its position changes.
- *Rotating an object* – The user can rotate an object by placing both the thumb and forefinger of one hand or the forefinger from each hand on the object and rotating the contact points. Coupling a rotation action with a movement action is trivial, as the

object positions itself to best match the relative positioning of the two points, given any movement.

- *Aligning an object* – By dragging an object that allows rotation to the edge of the desktop, the face that comes into contact with the edge can be aligned against it. This action is provided as a convenience to the user. The action is not an expected capability of the interface, but it is somewhat afforded by the fact that the display surface of the DiamondTouch device is lowered from the frame, leaving a raised edge against which objects could be aligned. To prevent clutter, once an object is aligned against the edge of the display, it is allowed to slide past the boundary.
- *Picking up an object* – By placing both contact points of one hand down and bringing them closer to each other, the topmost object between the two points is then picked up by that hand. Early trials showed that users often forgot whether or not they held an object, so an unobtrusive semi-transparent display of what each hand holds appears when an object is picked up (Figure 5).
- *Dropping an object* – By placing the thumb onto the surface followed by the forefinger, a held object can be placed back onto the desktop without invoking its action (in the case of pens, tape, etc.). Lifting the fingers immediately will only pick the object back up, but if the user spreads his or her fingers in the reverse of the picking up motion, the object will be dropped back onto the desktop.
- *Using an object* – Due to the variety of objects represented and the different ways one might use each object, there are three classes of object use supported by HabilisDraw

DT:

- *Pick up and use* – This involves picking up an object, such as a pen, and using it by placing the forefinger of the hand which holds the object down onto the surface. For a pen, this draws a line. For the tape, it marks a green line between the start of the motion and the end of the motion, under which all intersecting objects are joined. For an inkwell, this “adds ink” to the target object, which affects different objects accordingly: paper is colored completely, pens change their ink color, empty inkwells are filled with ink, and filled inkwells change colors gradually to simulate mixing inks.
- *Touch* – Touching some tools causes an action to be performed. The cutting arm cuts all paper intersecting its blade when touched. In the case of an inkwell, touching it with a pen in hand will change the pen’s ink color, simulating dipping the pen. For the stack of paper, touching it will instantiate a new sheet of paper, simulating dragging a sheet off the top of a limitless stack. Finally, holding a piece of paper or inkwell and touching it to the trash can will dispose of the paper or empty the inkwell, respectively.
- *Drag onto* – Dragging is only supported by the trash can. Dragging a piece of paper onto the trash can will throw the paper away.



*Figure 5: Holding an object (in this case, a pen) shows a transparent “iconic display” of the object in hand.*

### 3.4.2 Code Structure

The software side of HabilisDraw DT is coded in C++, using OpenGL, Microsoft Windows API, and DirectX along with the MERL DiamondTouch SDK v1.2 for display and input. No code was recycled from prior projects or external libraries. The class structure is minimally hierarchical, taking more of an interface layer approach. The structure of the major functional classes in the application is described in the following outline.

#### *Top-level object classes*

- *Renderer* – The renderer class handles displaying objects and information. It additionally provides certain functions that affect the global object set.
  - *Overlay* – The overlay class is a subclass of the renderer, which allows for the display of information on top of the object environment. It is responsible for displaying text and other informational overlays.

- *DiamondTouch* – The DiamondTouch class packages input from the DiamondTouch device into a data structure that can be polled from other classes.
- *DirectInput* – The DirectInput class wraps Microsoft’s DirectInput interface to provide support for basic keystroke input. When the DiamondTouch is not functioning properly, it also provides debug mouse input.
- *Hand* – The hand class links to the renderer and input classes to provide and interpret gestural input into commands for the objects and renderer.
- *Object2D* – The 2D object class represents a single instance of an object in the environment. An important note is that this class encompasses both environment objects as well as objects that would be classified as “tools.” Object2D methods encompass most of the functions that affect a single object. Using the copyObject() function, a 2D object can generate an exact replica of itself, down to the custom edit texture.

### *Helper objects*

- *Matrix, Vector, and Point3/Point2* – The matrix, vector, and point classes serve simply to provide storage and mathematical operators for various data structures.
- *Font* – The font class wraps an OpenGL texture, style parameters, and font metrics into a general package for drawing 2D texture-mapped fonts to the overlay. Once a font is created, other fonts can “borrow” its texture to provide an instance of a font with different parameters that uses the same texture map to save on memory usage.

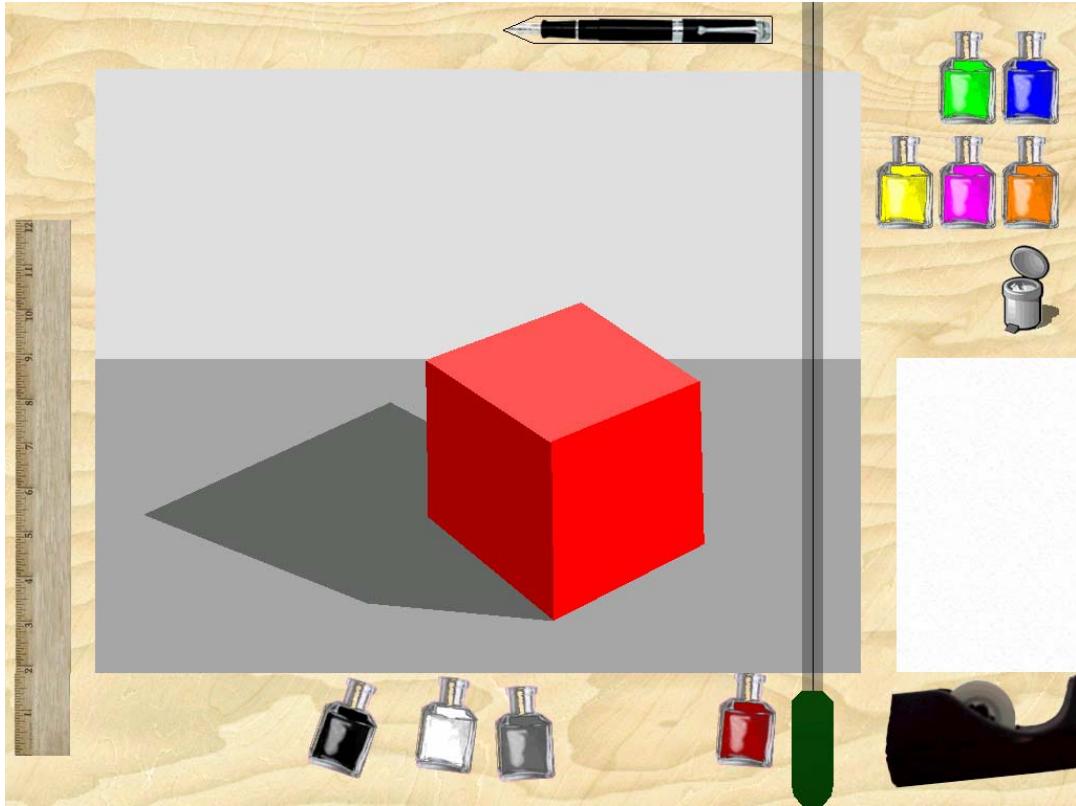
- *Monitor* – Used for debug purposes, the monitor class contains a position in 2D, a pointer to a font, and a void pointer and pointer type to designate a value in memory to monitor. Once instantiated and registered with the overlay, a monitor displays the current value of the data to which it points.
- *CoordList* – The coordinate list class stores and maintains a list of 2D points. Every 2D object maintains a list of its vertices stored in a coordinate list in order of right-hand winding (counter-clockwise).
- *Timer* – The timer class keeps an instance of the Microsoft Windows millisecond timer and helps maintain current and delta values for timing calculations.

### 3.4.3 *Implementation notes*

As mentioned before, the graphics in HabilisDraw DT are programmed in OpenGL using Windows API for windowing functions. All visible objects except for informational displays are instances of the Object2D class displayed by the Renderer class. The renderer maintains an ordered list of objects from bottom to top, drawn in a painterly fashion to obviate the need for depth buffering. Each object maintains a base texture, specified at instantiation, to which it can be reset. In addition to this, each object specified as “drawable” keeps an RGBA “edit texture,” which begins as a copy of the base texture. This is an editable texture which accumulates all ink operations performed on the object. When the pen is used on a drawable object, the object is transformed back to the position (0, 0) with no rotation and the pen’s position is transformed to the object’s coordinate space. All objects above the object in question are rendered into the stencil buffer to prevent the pen from

marking underneath an occluding object, and a line is drawn to the object’s edit texture at the pen’s transformed location. The drawing process is then iterated on all objects positioned under the pen. This process allows the pen to draw correctly on any drawable object in any orientation and only on the topmost object at any given pixel.

The process of maintaining edit textures for all drawable objects and iterating through all objects under a given point with the draw operation causes HabilisDraw DT’s pen-drawing functionality to be very processor- and memory-intensive. When an object is bisected with the cutting arm, the object’s edit texture is copied over to the new object resulting from the cut and new texture coordinates are calculated. Since edit textures are at full resolution and textures only support dimensions in powers of two, cutting an 800x600 pixel would result in a  $1024 \times 1024$  ( $2^{10} \times 2^{10}$ ) 32-bit texture being doubled with each cut. To prevent a geometric climb in texture memory requirements with each cut, the texture copy operation is designed to recalculate the next highest power of two for each dimension of the new piece of paper and crop the texture to match.

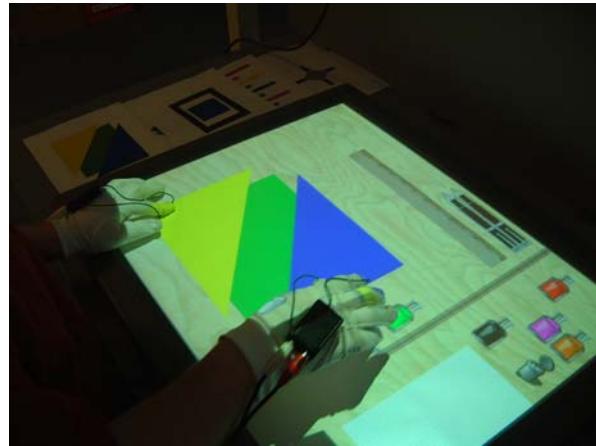


*Figure 6: An expert drawing done with HabilisDraw DT.*

#### **4. EXPERIMENT**

To explore the feasibility of HabilisDraw DT’s design principles, I conducted an observational study across twelve participants of varying ages and backgrounds. Subjects were shown the default HabilisDraw DT desktop and the various tools were described briefly. A list of available actions was then provided and remained available to the subject for the course of the experiment. Once the subject was satisfied with the description of the system, he or she was put to a series of basic tasks to help acclimate him or her to the basics of operating the interface and interacting with the tools. While performing the tasks, the subjects’ behavior was recorded in photographs, text, and screenshots. When confused or lost, users were encouraged to try and find the solution before help was provided. The

subjects were asked to perform the following tasks, then fill out a questionnaire about their performance.



*Figure 7: A user performing a pattern matching task in HabilisDraw DT.*

1. Drag a piece of paper off the stack
2. Pick up a pen in one hand.
3. Pick up an ink bottle in the other hand.
4. Make a pen mark on the paper.
5. Pour ink on the paper.
6. Fill an empty ink bottle with a color.
7. Blend the new ink bottle color with another color of ink.
8. Change the pen color to the new color and test it on the paper.
9. Empty the new blended ink into the trash.
10. Rotate the paper 90 degrees, align it with the edge of the desktop, and cut it in half with the cutting arm.

11. Rotate one piece of the paper 90 degrees and tape it to the other piece.

12. Throw away the paper

13. Drag the ruler down and make a pen mark along its edge.

*At this point, the program was reset and the user was provided a clean desktop.*

14. Choose two of the provided patterns and copy them as closely as possible.

*The program was reset after each pattern.*

15. Draw or otherwise “create” two of the following images however you choose:

House

Sailboat

Person (Stick figure/humanoid)

Telephone

*The program was reset after each drawing.*

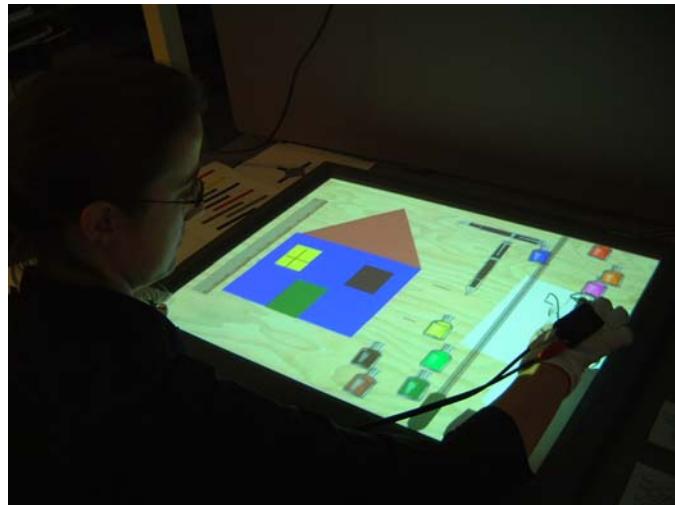
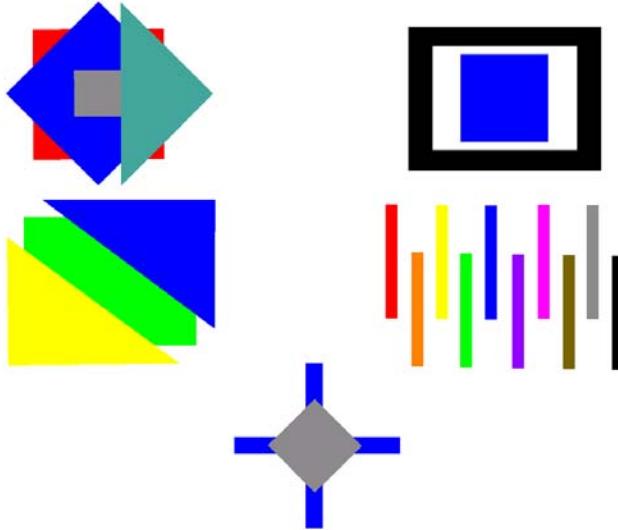


Figure 8: A user creating a house in HabilisDraw DT.

The patterns provided for step 14 are shown in Figure 9. The questionnaire is provided in Appendix A and responses are provided in Appendix B. Subjects generally completed the test in 30-60 minutes, though some took longer. The time spent on the test does not tell us anything about the interface, however, because the users that took longest spent more time carefully crafting their drawings while the faster users tended to approach their tasks with less time and effort spent on details.



*Figure 9: The selection of experiment patterns.*

## **5. RESULTS**

The study provided many interesting insights into how users approach the drawing task using the HabilisDraw DT interface and how the interface might be used or improved in the future. Some of the more pertinent observations made during the experiment will be listed in this section. The observations will be divided into the following categories:

1. Actions – This section details observations about how users performed the actions supported by the interface.

2. Objects – This section details observations about how users dealt with the objects and tools in the interface.
3. Interface – This section details observations about how users interacted with the interface itself.
4. Approaches – This section details observations about how users approached the tasks with respect to the interface and environment.

## 5.1 Action Observations

- Despite the fact that HabilisDraw DT's action gestures were designed to be familiar and intuitive (e.g. picking up an object by pinching it and lifting the hand off the surface), some people confused the pick-up and put-down gestures, trying repeatedly to pick up an object with the put-down action, for example.
- Most subjects used the edge alignment capability sparingly, despite being made aware of the ability early in the experiment.
- Subjects represented both one- and two-handed rotation almost equally, but each user tended to prefer one or the other.
- Of the two methods to dispose of unneeded paper (dragging onto trash, picking up and touching to trash), many users either preferred or only discovered one approach, but several used both methods interchangeably.
- However, of the two methods to change a pen's ink color (dipping in ink, pouring ink onto pen), most only used one of the methods throughout the experiment.
- The method of using the tape (pick up, then drag a line) was unfamiliar to many users at the start—several tried tapping the tape on objects before figuring out the

supported method. Sometimes tapping the tape on an object yielded the desired results anyway.

- Some users discovered supported actions by systematic trial-and-error. For example, to empty an inkwell into the trash, one user tried dragging the inkwell onto the trash, then picked up the inkwell and tried to place it on the trash repeatedly until he accidentally emptied the ink into the trash by placing his index finger down first. Thus the user “learned” that putting both fingers down on the trash while holding the ink seemed to empty the inkwell. For the next several attempts to empty an inkwell, the user would pick up the inkwell and put both fingers down on the trash repeatedly until the inkwell emptied. One such user forgot how to empty an inkwell and instead diluted the ink with a different color.
- Two out of twelve subjects used the cutting arm by pressing down on the handle and sliding the index finger up the “blade” until past the target object. Since the gesture began with tapping the cutting arm handle, while sliding up the blade did nothing, the action was still successful. Thus the subjects “learned” this invented action and continued to use it for the rest of the experiment.
- Some subjects tried to capture and transfer ink using only their hands, tapping the ink then tapping a pen or paper. Others tried dragging the ink onto an object.
- One user mixed ink by tapping rapidly, not realizing that it was a continuous process (tap and hold).

## 5.2 Object Observations

- Some subjects were frugal about paper use despite the limitless supply, saving larger scraps for use later.
- On the pattern-matching task, two of the subjects took the printed pattern and placed it on the display surface as a guide for matching the scale exactly.
- Several users did not expect the ruler to constrain the pen line, instead using it as a guide to draw a straight line freehand.
- Only one user used the pen as a demarcating tool, using it to mark where to cut a piece of paper to make a square. All other users treated it as an effective tool for creating marks or drawings.
- Two users found that two pieces of similarly-colored paper on top of each other were hard to distinguish from each other and used ink as a demarcating tool to better differentiate the pieces while they were near or on top of each other.
- Several users cut a shape out of paper for use as part of a drawing or pattern and used the first piece as a guide to cut more shapes like it.
- During development, the ruler was considered to be borderline unnecessary due to expectations that it would only be used as an unwieldy straightedge, but many of the more careful users used it regularly for measurement.
- Several users expected the ink to act as a flood fill, only filling the space outlined by pen ink. This occasionally proved catastrophic after a lengthy drawing process.

- No users ever used paper as a mask or stencil. Paper was used only as an object the vast majority of the time, occasionally being used as a guide (or *instrument*) for cutting other shapes.

### 5.3 Interface Observations

- After very preliminary testing, it became apparent that users forgot what was being held in each hand. Because of this, semi-transparent iconic displays of hand contents were implemented in the lower-left corner of the desktop. However, when the icons appeared, despite having “Left hand:” or “Right hand:” above the icon and a box around it, some users tried to pick up or perform actions on the icons as if they were the real object.
- Many users, despite the iconic displays, still forgot that they were holding objects in hand, trying and failing to manipulate other objects. In other cases, they would forget that the iconic displays existed, then try to empty an inkwell and not know if the action was successful or not (despite the iconic display showing an empty inkwell in hand).
- Several users tried using their middle fingers to move and rotate objects despite being told that their only effective contacts were on the thumb and index finger of each hand.
- One user, likening the interface to finger painting, remarked, “I feel like a little kid.”

- One user, after first manipulating sheets of paper, expressed his approval of the interface, saying, “It’s intuitive,” and, “It’s great when a program does what you want it to.”
- One user lamented the lack of some common tools, saying, “You’ve got no tools to make shapes.”
- One user placed a sheet of paper on top of the cutting arm handle and became confused about how to cut the paper since the handle was obscured.
- One user expressed a preference for keeping the desktop clear of unnecessary objects. Most users were only concerned with keeping an “active area,” in which construction or drawing was taking place, clear from debris and obstruction.
- Some users were unsure of whether or not the cutting arm had cut the paper when they pressed the handle. Several tried cutting several times, expecting some sort of feedback, before checking by hand if the paper had been cut.
- Many subjects first expected tools to behave as they do in mouse-driven interfaces, with simple click or click-and-drag motions. Some tried picking up and putting down by tapping an index finger on an object. One user tried double-tapping when other actions failed.
- Picking up pens and inkwells occasionally proved difficult for many users due to the awkward posturing of the gesture while reaching across the surface.

## 5.4 Approach Observations

- A small number of users favored one hand tremendously, only using a second hand when instructed to do so. This occasionally led to needless and highly inefficient serialization of tasks.
- Conversely, some subjects used both hands even when unnecessary. There are two common examples of this behavior: moving an object with both hands without needing or intending to rotate it, and providing a stabilizing context with the non-dominant hand to support the dominant hand, usually by holding a ruler while drawing against it. The latter example clearly supports Guiard's kinematic chain theory. Unfortunately, HabilisDraw DT cannot support this approach well, since hardware imprecision causes "stabilized" objects to jitter. The only way to ensure an object will remain stable is to leave it on the desktop and not touch it. In cases where the object that needs to be stable is being acted on by some other object, this is often counter-intuitive.
- Some users used spatial partitioning to differentiate objects. For example, one user had particular difficulty mixing an inkwell, so he moved it to the side when it was mixed to satisfaction so he would not accidentally change its color later.
- Several subjects positioned the ruler perpendicular to the cutting arm for precise measurement of cuts. This could be considered a type of composition.
- Some users optimized tasks by serializing in order of action. For example, one user cut a strip, cut the strip rapidly into blocks, then inked all of the blocks in quick succession.

- A popular approach taken by users was to select and master a subset of tools and actions and rely almost exclusively on them. For example, one user never used the cutting arm except when instructed to do so.
- One user devised a unique approach to creating round objects: he “lathed” a circle by rapidly tapping the cutting arm handle while rotating the paper and positioning it under the arm. The effect was of a constantly-cutting boundary against which paper could be “shaped,” much like Raisamo’s shaping stick.
- After “lathing” out a circle, the user consolidated the clean-up task by taping all of the shredded debris together before picking it up and throwing it away.
- One subject drew the patterns out with pens. All other subjects composed them with paper.
- Several subjects preserved their work’s intermediate states by taping everything together periodically.
- About half of the subjects completed the final drawing task by constructing the objects out of paper. About a third of the subjects drew the objects on paper. The remaining subjects constructed the objects out of paper, but added details with the pen.
- Some users drew directly on the desktop when they reached the edge of the paper on which they were drawing.
- One user prefabricated patterns by creating the necessary parts, then positioning them.

## 6. ANALYSIS

**Table 1: A qualitative evaluation drawing environment interactions in HabilisDraw DT with respect to standard direct manipulation interfaces.**

Technique/Procedure	Interface Support	Visibility	Efficiency
• Moving an object	*	++	++
• Rotating an object	++	++	++
• Picking up a tool/object	-	*	-
• Putting down a tool	-	*	-
• Using a tool	-	*	*
• Drawing a freehand line	*	*	*
• Drawing a straight line	-	-	--
• Cutting an object	-	+	++
• Filling an object with one color	*	*	*
• Selecting a color	*	+	*
• Editing a color	*	+	-
• Joining two or more objects	*	+	+
• Deleting an object	*	++	*

Legend:

- : Significantly lower
- : Slightly lower
- \* : Minimal difference
- + : Slightly higher
- ++ : Significantly higher

From the observations made in this experiment, it becomes apparent that in some ways, the tool use model can improve both learnability and the efficiency of interaction. Table 1 shows a list of the actions supported by HabilisDraw DT along with a qualitative evaluation of its performance with respect to standard direct manipulation interfaces (i.e. paint programs) in three categories: interface support, visibility, and efficiency. Interface support evaluates the actual physical interface's ability to support the action and whatever user interactions are required to execute it. Rotating an object scores highly in this field because most paint programs lack the degree of input required to rotate intuitively, while many actions differ minimally because using a tool by tapping a finger or clicking a mouse are effectively equivalent. Visibility describes the interface's ability to intuitively convey the required procedure to perform the action. High visibility implies ease of learning an action. Drawing a straight line is ranked lower than the standard interface because in HabilisDraw DT, it requires tool composition while most programs have a specialized line tool. Finally, efficiency describes how quickly the user can satisfactorily perform the action. Actions that would otherwise require navigation through menus or use of composite or specialized tools rank low with respect to efficiency. As the table shows, HabilisDraw DT fares well in visibility and is fairly balanced in efficiency, but generally lacks good interface support due to the mapping from three-dimensional physical interactions to a two-dimensional input device. There are numerous benefits stemming from the application of the tool use metaphor to the drawing environment, but there are also several drawbacks to a tool-based model as well as one very important caveat concerning the implementation of such a model.

One of the greatest benefits of HabilisDraw DT's interaction model is that users are naturally comfortable with spatial consistency, and most users acclimate well to the

interface's respect for physical rules such as persistence, visible object status, manipulability, and locality. Most users quickly adapted to the ability to partition tools and objects spatially. When tools respect the principle of locality, the user can rely on an object's distanced position to have an appropriate effect towards preserving that object's state; that is, when an object is set aside, it is relatively safe from accidental changes caused by actions outside of its locality. Many users also adjusted well to the dangers inherent to physical manipulability, preserving desired relative object orientations by taping them together as an intermediate step in the creation process. These actions are all completely consistent with real world behavior, supporting the claim that developing a strong physical-virtual interaction correlation can produce a relatively shallow learning curve, at least for actions that sufficiently parallel common real world interactions.

By establishing a mental model parallel to the user's concept of real world actions, support for basic tool composition and task iteration proves to be relatively intuitive for most users. Use of the ruler as an instrument was commonplace in user trials, as one might expect with a real world drawing task, and combining the ruler with the cutting arm to perform guided cuts came naturally to several users. In fact, for many, the virtual composition of ruler and cutting arm surpassed the convenience of doing so in the real world when users found that they could place the ruler under the cutting arm and use it to guide the cutting process without damaging the virtual ruler. Some users even combined the virtual and real models by using the printed patterns as tangible tools in the interface, placing the paper printout on the DiamondTouch surface and using it as a guide for measurement and color matching.

While supporting tool affordances provides many clues that help users learn how to operate tools, it can yield both good and bad effects with respect to novice user interactions. Support for visual affordances, when handled properly, makes an interface far more usable and intuitive. When an object can be held, it is naturally best to represent it in a fashion that implies an affordance for being picked up. Similarly, tools that operate with certain constraints are best represented with some indication of these constraints; for example, a square compass or a cutting arm with a misleading portrayal of the blade (or no such portrayal at all) would only be confusing and difficult to understand. As long as all affordances are valid and fully supported, they increase the amount of information about the interface and its operation that the user can gather visually. HabilisDraw DT’s trash can is an example of a well-supported set of affordances. Users can pick up a piece of paper and “use” it on the trash can to throw it away or they can simply drag paper onto the trash can and release it to throw it away. The other side of the coin, however, is that not all affordances are intentional or fully supported in an interface. In fact, sometimes fully supporting all affordances is either implausible, inconsistent, or contrary to the system’s design. While the ideal interface should never result in an attempted action that fails to accomplish its goal, there are times it cannot be avoided. Since HabilisDraw DT is a digital interface, some users carry over perceived affordances from the set of digital tools provided by a paint program. As a result, some users attempted to activate a tool’s functionality in HabilisDraw DT by tapping, dragging, or even “double-clicking” it. The perceived affordance is for various mouse actions, but when these are not supported by the interface (and for good reason), they only lead to confusion.

Besides false affordances, there are other aspects of the tool-based model that do not necessarily translate well to a virtual drawing environment. Due to the necessity of projecting the interface on a two-dimensional display, it is extremely difficult to input or output any information in the missing third dimension. This limitation creates difficulties in providing adequate feedback and necessitates approximated actions for such tasks as picking objects up, putting objects down, taping, and operating the cutting arm. As a result, several users had difficulty learning to use the cutting arm and mastering picking up and putting down objects.

Most of the inadequacies of HabilisDraw DT's application of the tool-based interaction model can be summarized as one very important caveat for those who intend to apply a similar tool use model to any interface: consistency is paramount. Violations of the underlying model principles are often the source of the greatest impediments to learnability and ease of use. One of the most common problems for subjects from non-technical backgrounds was confusion about the iconic displays of hand contents. These were added as a response to a lack of feedback about the user's status, but in exchange for providing this feedback, the principles of locality, object status, and manipulability were violated. Since the rest of the system behaved according to these principles, a significant number of users saw the icons as manipulable objects and as such, tried to perform such actions as inking the icon of a pen or dipping a pen in the icon of an inkwell. The icons have no status as objects and as such are not manipulable, but in violation of the model, they are displayed similarly to objects without manifesting any of the attributes of an object.

**Table 2: Quantitative overview of survey demographics and responses**

<b>Demographics</b>	
Male/Female ratio	7 Male / 5 Female = 1.4:1
Average age	24.7 years old
Right/Left hand ratio	9 Right / 3 Left = 3:1
Computer experience range	4-25 years
Average computer usage per week	46.9 hours per week
<b>Responses</b>	
Had artistic background	5/12 = 41.7%
Considered bimanual input helpful	11/12 = 91.7%
Used non-dominant hand significantly	5/12 = 41.7%
Had notable difficulty with software interface	6/12 = 50%
Attempted unsupported actions	8/12 = 66.7%
Found some tools unnecessary	3/12 = 25%
Satisfied with performance	11/12 = 91.7%
Satisfied with overall system	12/12 = 100%

## **7. CONCLUSION**

In this paper, I have described in detail the background for the fundamental design concepts of HabilisDraw DT, the history of the system, and the hardware on which it was built. I have outlined the structure and concept of the software and described an observational study and the results thereof. HabilisDraw DT's application of the principles of tool use to a simulated drawing environment have shown some of the potential benefits of

a tool-based interaction model with respect to direct manipulation interfaces and simulations of real world environments. The results of the observational study urge further exploration of the benefits of a persistent, physically consistent user space in which objects respect the characteristics of tool use outlined in this paper. Additionally, the study shows some of the drawbacks and difficulties of applying the model to an interface.

With respect to the learnability and usability of an interface, HabilisDraw DT shows that careful application of a tool use model can help novice users develop skills within the interface quickly and naturally. This is consistent with the trend towards perfect simulation of an environment in that, given a theoretical system that emulates an environment perfectly and supports all physical interactions within that environment, any virtual task within that system is effectively reduced to the corresponding physical task and the time spent learning the interface is zero. As the tools and environment are simulated more and more realistically, the time required for a user to learn how to use those tools decreases and the user's interaction style tends more towards the already familiar real world interaction style with which he or she is comfortable.

However, in implementing such principles, there are several drawbacks. As the simulated environment tends towards complete simulation of its physical counterpart, the benefits of having developed the system in the first place diminish. A perfect replica of the drawing task has no support for such physically unsupported as undo, saving images, printing images, copying images and objects, etc. One of the reasons graphic artists use Adobe Photoshop and similar programs instead of drawing on physical media and scanning the results is that programs that do not strive to simulate the drawing task can extend beyond the

drawing task and provide functionality only available in a virtual domain. This functionality is entirely incompatible with direct simulation.

If a system does intend to simulate tool interactions, then it is important to enforce strict adherence to the principles implemented in the system. A violation of these basic principles can do more harm than good at times, such as the iconic displays in HabilisDraw DT that led many users to believe they could interact with the icon of objects in hand. Unfortunately, due to the nature of the tool model, this can limit the functionality of a given tool, depending on the style and strictness of simulation.

In conclusion, HabilisDraw DT shows that there are benefits to applying a tool-based metaphor to simulated environments such as the drawing scenario implemented here. Learnability and usability can be improved and supporting rich user interaction via bimanual support and a direct manipulation model can help in mapping natural real world interactions to virtual tools. The extent to which the model is implemented in HabilisDraw DT is unrealistic for practical purposes, but in doing so, the system shows the drawbacks inherent in an overuse of the metaphor: that is, a need for strict adherence to the principles of the model and a tendency to lose support for the benefits of using a digital representation in the first place. In the future, HabilisDraw DT could be extended and refined much like the original HabilisDraw into a more powerful and less strictly tool-based version 2.0, which may very well serve to bridge the gap between an impractical experimental interface and a fully viable novel interface.

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## APPENDIX A: Study Questionnaire

### HabilisDraw DT Usability Questionnaire

Name	_____
Major	_____
Age	_____
Gender	_____
Handedness	_____
For how many years have you used computers?	_____
About how many hours per week do you use a computer?	_____
Describe your artistic background, if any.	_____
Did you feel that being able to use both hands was helpful?	_____
How much did you use your non-dominant hand?	_____
Any difficulty using the interface (not counting hardware difficulties)?	_____
Did you try to do anything that was unsupported by the interface?	_____
Would you suggest any additions (tools, functionality) to the interface? (missing something expected)	_____

Did any tools or functionality seem unnecessary?

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How did the interface change the way you approached the creation task with respect to real world?

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How did the interface change the way you approached the creation task with respect to paint programs?

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What did you find easier to do in HabilisDraw DT than in a normal paint program?

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What did you find harder to do in HabilisDraw DT than in a normal paint program?

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Are you satisfied with your performance in the creative tasks?

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Overall impressions?

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## APPENDIX B: Questionnaire Responses

### HabilisDraw DT Usability Questionnaire

Name	<input type="text" value="REDACTED"/>	
Major	CS	
Age	27	
Gender	Male	
Handedness	Right	
For how many years have you used computers?	+20	
About how many hours per week do you use a computer?	40	
Describe your artistic background, if any.	Basic art in high school years	
Did you feel that being able to use both hands was helpful?	yes	
How much did you use your non-dominant hand?	little, but the times I used it I felt it very important to the task I was using it for	
Any difficulty using the interface (not counting hardware difficulties)?	<ul style="list-style-type: none"><li>- inability to use the pen for micro tasks or with high accuracy</li><li>- couldn't flip pieces of paper over</li><li>- couldn't remove hands without inadvertently affecting a piece of paper</li></ul>	
Did you try to do anything that was unsupported by the interface?	yes, flip a piece of paper basic cutting that did not divide a piece of paper into 2 distinct pieces	
Would you suggest any additions (tools, functionality) to the interface? (missing something expected)	<ul style="list-style-type: none"><li>Scissors</li><li>pin, then to anchor a piece of paper to a point</li><li>maybe removable tape to temporarily join 2 pieces of paper</li><li>eraser or paintbrush</li><li>color sampler (for erasing)</li></ul>	

Did any tools or functionality seem unnecessary?

no

How did the interface change the way you approached the creation task with respect to real world?

allowed quick disposal of waste material

How did the interface change the way you approached the creation task with respect to paint programs?

it didn't

- appreciated the line-up utility using edges.

What did you find easier to do in HabilisDraw DT than in a normal paint program?

cut pieces of paper into what I wanted +

compare different pieces to one another

What did you find harder to do in HabilisDraw DT than in a normal paint program?

draw with the pen

Are you satisfied with your performance in the creative tasks?

somewhat satisfied

couldn't micromanage as much as I sometimes wanted to

Overall impressions?

fun, nice to be interactive with materials

sometimes frustrating trying to line up pieces the way I wanted

### HabilisDraw DT Usability Questionnaire

Name	[REDACTED]	
Major	CPE	
Age	21	
Gender	Male	
Handedness	Right	
For how many years have you used computers?	13-14	
About how many hours per week do you use a computer?	120	
Describe your artistic background, if any.	Stick figures and composite shapes, no true artistic talent	
Did you feel that being able to use both hands was helpful?	Yes, much easier than using a mouse	
How much did you use your non-dominant hand?	Only to rotate and move objects when other hand held something	
Any difficulty using the interface (not counting hardware difficulties)?	Not using finger tip, difficulty dropping objects with getting fingers close together	
Did you try to do anything that was unsupported by the interface?	Tried to find a way to erase the desktop	
Would you suggest any additions (tools, functionality) to the interface? (missing something expected)	White out, scissors to cut curved lines (circles, arcs, snowflakes)	

Did any tools or functionality seem unnecessary?

not really

How did the interface change the way you approached the creation task with respect to real world?

task is slower, drew the easier patterns and objects

How did the interface change the way you approached the creation task with respect to paint programs?

had to cut and paint paper to create a shape rather than drawing with pens and ptbrushes.

What did you find easier to do in HabilisDraw DT than in a normal paint program?

cut shapes, blend colors, direct sense of size of object

What did you find harder to do in HabilisDraw DT than in a normal paint program?

making symmetric shapes (roof, etc)

Are you satisfied with your performance in the creative tasks?

to the best of my artistic ability

Overall impressions?

Wow! no more need to waste paper and paint, just printer ink

### HabilisDraw DT Usability Questionnaire

Name \_\_\_\_\_  
Major Industrial Engineering  
Age 22  
Gender Female  
Handedness Left

For how many years have you used computers? 12-13

About how many hours per week do you use a computer? 21

Describe your artistic background, if any.

Three years of art in high school, several other private classes for fun.

Did you feel that being able to use both hands was helpful?

Yes. I tend to be ambidextrous.

How much did you use your non-dominant hand?

40% of the time.

Any difficulty using the interface (not counting hardware difficulties)?

I was just slow to learn/remember. Otherwise it was fairly easy.

Did you try to do anything that was unsupported by the interface?

Tried to fill a shape with color, and it didn't work, but that may have been user error.

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

Eraser?

Did any tools or functionality seem unnecessary?

No.

How did the interface change the way you approached the creation task with respect to real world?

Tried to be more efficient. Tried to draw lines with ruler going same direction, then rotated 90° to draw all other lines.

How did the interface change the way you approached the creation task with respect to paint programs?

Colored things with pen instead of filling with paint.

What did you find easier to do in HabilisDraw DT than in a normal paint program?

No, but if I had more time to practice I might.

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Precision tasks weren't so easy.

Are you satisfied with your performance in the creative tasks?

Yes, for my first time.

Overall impressions?

Very cool from an ergonomics standpoint. Hey, I'm an IE, what can I say?

### HabilisDraw DT Usability Questionnaire

Name	<input type="text" value="REDACTED"/>	
Major	Comp Sci	
Age	> your age!	
Gender	female	
Handedness	left	
For how many years have you used computers?	~ 4	
About how many hours per week do you use a computer?	56+	
Describe your artistic background, if any.	I have had lots of drawing & painting practice including several drawing and painting classes,	
Did you feel that being able to use both hands was helpful?	yes, but it also led to some frustrating mistakes. for example I forgot I had ink in my hand and tried to move the paper...	
How much did you use your non-dominant hand?	50/50 right hand for picking up and moving ink and paper. (not for drawing).	
Any difficulty using the interface (not counting hardware difficulties)?	trouble picking things up (may have been hardware issue) but you do this a lot so it got a little frustrating	
Did you try to do anything that was unsupported by the interface?	<ul style="list-style-type: none"> <li>• Erase in pen</li> <li>• Change color of ink by tapping it on icon showing what's in your hand. (This seems logical to me)</li> </ul>	
Would you suggest any additions (tools, functionality) to the interface? (missing something expected)	<ul style="list-style-type: none"> <li>• Frizer</li> <li>• cutting w/out having to move paper (move the chopper?)</li> <li>• Difference tip (per tip) thicknesses</li> </ul> <p>In fact it might be easier if blade is on the left</p> 	

Did any tools or functionality seem unnecessary?

No  
Add more!

How did the interface change the way you approached the creation task with respect to real world?

yes. I made the image w/ 10 strips of paper.

Here I cut them one at a time, whereas, I would have chopped them all at once on a real paper cutter. But you can't hold more than 2 papers at a time and it would be really hard to stack 10 sheets neatly

How did the interface change the way you approached the creation task with respect to paint programs?

Two hands are nice, whereas in Photoshop you just have one cursor.

What did you find easier to do in HabilisDraw DT than in a normal paint program?

Sorry I misread  
Thought you wanted a general answer.

I think I depend on practice.  
But Hab is nice in that you can almost forget that you're using a computer!

Easier: sketching directly on screen (rather than w/mouse)

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Select objects (cause of 4th question on front page)

Are you satisfied with your performance in the creative tasks?

yes. The shadow of your hand makes it a little hard to draw precisely (along w/the glove). But the results weren't bad.

Overall impressions?

Great fun! Most of the interface was easy to use once I had some practice and much more engaging than a traditional mouse drawing interface.

### HabilisDraw DT Usability Questionnaire

Name \_\_\_\_\_

Major Biology, English, Spanish

Age 22

Gender female

Handedness Right

For how many years have you used computers? ≈ 17

About how many hours per week do you use a computer? 15

Describe your artistic background, if any.

Creative writing. Not much experience otherwise.

Did you feel that being able to use both hands was helpful?

Yes but a bit confusing to keep track of: I think I mostly used my right hand.

How much did you use your non-dominant hand?

Very little.

Any difficulty using the interface (not counting hardware difficulties)?

A little difficulty figuring out how to dip the pen and how to use the cutting arm, but once those were gotten past it was easy enough.

Did you try to do anything that was unsupported by the interface?

Yes: erase.

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

Erasure, ability to draw standard lines and shapes, freehand scissors, small icon when one's hand is put down to show what is in it.

Did any tools or functionality seem unnecessary?

2 pens

How did the interface change the way you approached the creation task with respect to real world?

Didn't change much, but I was under external time constraints. The feel was realistic though, as far as, for example, dragging paper and picking up pens.

How did the interface change the way you approached the creation task with respect to paint programs?

see above, I wasn't able to use standard shapes, which did force me to work a bit more with multiple sheets of paper

What did you find easier to do in HabilisDraw DT than in a normal paint program?

switch between colors, combine pages

What did you find harder to do in HabilisDraw DT than in a normal paint program?

keep track of where my tools were

Are you satisfied with your performance in the creative tasks?

Yes

Overall impressions?

cool

HabilisDraw DT Usability Questionnaire

Name

[REDACTED]

Major

CS

Age

20

Gender

M

Handedness

R

For how many years have you used computers?

25

About how many hours per week do you use a computer?

50

Describe your artistic background, if any.

web designer 3-4 years

Did you feel that being able to use both hands was helpful?

yes

How much did you use your non-dominant hand?

only for rotating

Any difficulty using the interface (not counting hardware difficulties)?

no

Did you try to do anything that was unsupported by the interface?

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

tasks

Did any tools or functionality seem unnecessary?

No

How did the interface change the way you approached the creation task with respect to real world?

Normally I would not create  
models in paper, but the interface  
made it easy

How did the interface change the way you approached the creation task with respect to paint programs?

see last answer

What did you find easier to do in HabilisDraw DT than in a normal paint program?

cutting shapes

What did you find harder to do in HabilisDraw DT than in a normal paint program?

draw

Are you satisfied with your performance in the creative tasks?

yes

Overall impressions?

YPS

### HabilisDraw DT Usability Questionnaire

Name 

Major Computer Science

Age 24

Gender Male

Handedness Right

For how many years have you used computers? 18

About how many hours per week do you use a computer? 40

Describe your artistic background, if any.  
Visual arts - middle school art class. That's a 10

Did you feel that being able to use both hands was helpful?  
Sometimes... when the right hand would malfunction  
Had to force myself to think about using both hands

How much did you use your non-dominant hand?  
15% of the time  
to 20%

Any difficulty using the interface (not counting hardware difficulties)?  
Nope.

Did you try to do anything that was unsupported by the interface?  
Use my middle finger... which actually kinda was supported

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)  
Compass!!! ☺ May be a protractor?

Did any tools or functionality seem unnecessary?

Nope

How did the interface change the way you approached the creation task with respect to real world?

Could have more precision in real world (scissors better than cutting arm)

How did the interface change the way you approached the creation task with respect to paint programs?

Uses objects ~~as~~ A LOT more as models as opposed to drawings

What did you find easier to do in HabilisDraw DT than in a normal paint program?

Rotate objects - ~~copy~~ objects - making own color palette

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Straight lines - circles

Are you satisfied with your performance in the creative tasks?

Yup

Overall impressions?

Excellent system - much more fun to use

HabilisDraw DT Usability Questionnaire

Name \_\_\_\_\_  
Major Industrial Engineering  
Age 21  
Gender Male  
Handedness Left

For how many years have you used computers? 13

About how many hours per week do you use a computer? 60

Describe your artistic background, if any.

None really. I like observing art but did not really consider myself artistic.

Did you feel that being able to use both hands was helpful?

For a new task like this, both hands were VERY helpful.

How much did you use your non-dominant hand?

More than I normally do. Maybe I was just more aware of using it

Any difficulty using the interface (not counting hardware difficulties)?

Putting down items took some getting used to.

Did you try to do anything that was unsupported by the interface?

I tried to "pick up" the cutting arm.  
Trying to hold the ruler while drawing a straight line caused stuff to jump.

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

More fingers if anything.

Did any tools or functionality seem unnecessary?

Nope

How did the interface change the way you approached the creation task with respect to real world?

It didn't really.

How did the interface change the way you approached the creation task with respect to paint programs?

Multiple sheets of paper were nice & pasting them together was cool!

What did you find easier to do in HabilisDraw DT than in a normal paint program?

The ability to use your hands instead of a mouse.

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Finely detailed movements.

Are you satisfied with your performance in the creative tasks?

Sure.

Overall impressions?

I loved it & want one now.

### HabilisDraw DT Usability Questionnaire

Name [REDACTED]

Major CSC

Age 21

Gender F

Handedness Right

For how many years have you used computers? ~15

About how many hours per week do you use a computer? 40 - 60

Describe your artistic background, if any.

Art in elementary school + middle school  
3 years art in high school including AP Art  
spent lots of time drawing for fun in HS

Did you feel that being able to use both hands was helpful?

Sometimes, I mostly used my right hand

How much did you use your non-dominant hand?

not much

Any difficulty using the interface (not counting hardware difficulties)?

the ruler was difficult & sometimes dropping things could be difficult

Did you try to do anything that was unsupported by the interface?

no

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

maybe a line drawing tool besides the ruler

Did any tools or functionality seem unnecessary?

the ruler wasn't too helpful - it was easier to cut up paper and tape them together.

How did the interface change the way you approached the creation task with respect to real world?

I used cut up paper & tape to create things rather than draw them. It is a bit difficult to draw a 1 pixel line with a finger.

How did the interface change the way you approached the creation task with respect to paint programs?

I was able to use paper to create things, with paint programs you can only draw - and not use

What did you find easier to do in HabilisDraw DT than in a normal paint program?

change colors and manipulate tools

What did you find harder to do in HabilisDraw DT than in a normal paint program?

draw a straight line

Are you satisfied with your performance in the creative tasks?

sure

Overall impressions?

very cool!!

HabilisDraw DT Usability Questionnaire

Name

[REDACTED]

Major

Applied Math, Biology

Age

22

Gender

F

Handedness

R

For how many years have you used computers?

11

About how many hours per week do you use a computer?

21

Describe your artistic background, if any.

music background, art class in 9th grade (8 yrs ago).  
Art lessons as a child.

Did you feel that being able to use both hands was helpful?

Yes.

How much did you use your non-dominant hand?

pretty frequently. I use my L hand regularly though  
with piano & french horn

Any difficulty using the interface (not counting hardware difficulties)?

yes - trying to figure out when things had interacted  
properly ... like trashing something, taping something  
& changing pen ink color

Did you try to do anything that was unsupported by the interface?

my paper sometimes ran away from me, try  
to pick up more than one object at a time

Would you suggest any additions (tools, functionality) to the interface? (missing  
something expected)

how to cut a rounded shape, how to erase

Did any tools or functionality seem unnecessary?

extra pen.

How did the interface change the way you approached the creation task with respect to real world?

none that I know of... sorry.

How did the interface change the way you approached the creation task with respect to paint programs?

I stink at ms paint. I did as well with this interface as I generally do with paint

What did you find easier to do in HabilisDraw DT than in a normal paint program?

once I got used to it & if the gloves fit better.

cut, rotate papers

What did you find harder to do in HabilisDraw DT than in a normal paint program?

change objects.

(SWITCH ACTIVE TOOL)

Are you satisfied with your performance in the creative tasks?

yes.

Overall impressions?

cool.

### HabilisDraw DT Usability Questionnaire

Name \_\_\_\_\_  
Major Computer Science  
Age 22  
Gender Male  
Handedness Right

For how many years have you used computers? 15

About how many hours per week do you use a computer? 50+

Describe your artistic background, if any.

I enjoy drawing recreationally, but I have no formal training

Did you feel that being able to use both hands was helpful?

Yes, especially with rotating objects

How much did you use your non-dominant hand?

Significantly less than my dominant hand; only really used it for rotations & manipulation

Any difficulty using the interface (not counting hardware difficulties)?

Not really, it was very intuitive, especially w/ cutting out shapes; additive color model w/ ink was initially confusing

Did you try to do anything that was unsupported by the interface?

Not that I noticed

Would you suggest any additions (tools, functionality) to the interface? (missing something expected)

Maybe some variation in pen width, wider array of tools (or a palette), maybe a compass; ability to untag objects

Did any tools or functionality seem unnecessary?

Not really

How did the interface change the way you approached the creation task with respect to real world?

More focus on ~~making~~ shapes by cutting and pasting  
than I would in real world (although I guess I could have just used the ruler)

How did the interface change the way you approached the creation task with respect to paint programs?

Had to recognize the real world metaphor being presented  
(which was almost immediately obvious); more direct manipulation of canvas.

What did you find easier to do in HabilisDraw DT than in a normal paint program?

Object rotation & transformation; layer switching

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Pen drawing; hard to color in arbitrary shapes

Are you satisfied with your performance in the creative tasks?

Definitely

Overall impressions?

A lot of fun to use and very intuitive

### HabilisDraw DT Usability Questionnaire

Name	[REDACTED]	
Major	English	
Age	41	
Gender	M	
Handedness	R	
For how many years have you used computers?	12	
About how many hours per week do you use a computer?	40	
Describe your artistic background, if any.		
None		
Did you feel that being able to use both hands was helpful?		
yes - although I did not do it much, I can see that as I got more coordinated, I might want to do several things at once - as they become automatic		
How much did you use your non-dominant hand?		
Very little - but I think this is because I was trying to understand how things worked - and so did not try two tasks at once.		
Any difficulty using the interface (not counting hardware difficulties)?		
Within five minutes or so I felt comfortable and was interested in trying to apply and extend what I'd learned.		
Did you try to do anything that was unsupported by the interface?		
No - but I stuck to basics		
And I did make one mess - and wanted to "undo" it.		
Would you suggest any additions (tools, functionality) to the interface? (missing something expected)		
Some way of undoing or taking back a mistake		

Did any tools or functionality seem unnecessary?

No. Once I got started I could extend the basic principles. The tape was very easy once I had a sense of how elements related.

How did the interface change the way you approached the creation task with respect to real world?

I could see that sometimes I'd want to draw and sometimes I'd want to cut and tape pieces of paper

IT behaved like tape

How did the interface change the way you approached the creation task with respect to paint programs?

I don't have much experience with such programs — though I got further in a few minutes here than I have ~~had~~ with most conventional interfaces

What did you find easier to do in HabilisDraw DT than in a normal paint program?

yes — but my experience with such programs is limited — or perhaps yes — because my experience of them is limited and so this approach seemed less artificial

What did you find harder to do in HabilisDraw DT than in a normal paint program?

Not enough experience to say

Are you satisfied with your performance in the creative tasks?

yes — I was surprised to be able to match the model images so quickly

Overall impressions?

very interesting I think I could work very rapidly w/ this interface  
After ~~using~~ using it for an hour or so.